A Thesis

entitled

Development of a Methodology for Prioritization of Transportation Projects involving Multiple Assets

by

Bhupesh Raj Joshi

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Master of Science Degree in Civil Engineering

Dr. Eddie Y. Chou, Committee Chair

Dr. Liangbo Hu, Committee Member

Dr. Habib A. Kaake, Committee Member

Dr. Amanda Bryant-Friedrich, Dean
College of Graduate Studies

The University of Toledo

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An Abstract of

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In a present situation of transportation agencies, fund for different construction and maintenance projects in transportation is limited. So, there is a need to maintain the existing assets. Highway agencies need to justify the use of fund. This research focuses on a methodology to develop a web based transportation asset management trade-off tool to support the data driven decision at the project level.

The performance of the transportation system depends on the performance of multiple assets such as pavements and bridges. Therefore, there is a need for a method to determine the weight of multiple assets within a project to determine a single index showing the importance of the project. This index helps to prioritize all the projects being considered. Different objectives for defining the asset weight with the range of values for their criteria weight is defined. The Analytic Hierarchy Process (AHP) which was used in this research can incorporate both the quantitative and qualitative objectives. It focuses on developing a project level multi-asset prioritization tool that helps decision makers to justify the project selection decisions. Pavement and bridge are the two major assets in the roadway network. The project level prioritization is carried out using the data for these two assets. The AHP method uses the available data

for different criteria for pavements and bridges to calculate the relative priority weight of asset. The decision support tool is developed in a web based platform using vb.NET and the pavement and bridge data is provided by ODOT to rank the projects in the work plan.

Data driven results following a subjective comparison of the criteria will ultimately give the ranking of the projects. Decision makers can analyze the various selection criteria to change the schedule, add new projects, postpone or prepone the projects considering all the socioeconomic factors related to the project. The flexible framework of the web tool can also be modified or adapted to accommodate the addition of objectives or specific measures.

I dedicate my thesis to my late grandfather whose blessings are always there for me to encourage!!

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List of Abbreviations

AASHTO ....American Association of State Highway and Transportation Officials
ADT ....Average Daily Traffic
ADTT..........................Average Daily Truck Traffic
AHP............................Analytical Hierarchy Process

GA..............................General Appraisal

MAUT.........................Multi-Attribute Utility Theory

ODOT ....Ohio Department of Transportation

PCR............................Pavement Condition Rating

TAM...........................Transportation Asset Management

Chapter 1

Introduction

1.1 Transportation Asset Management

Transportation asset management is the process of optimizing and performing a cost effective maintenance and rehabilitation of the physical assets. American Association of State Highway and Transportation Officials (AASHTO) in AASHTO (2013) defines transportation asset management as "a *strategic and systematic process of operating, maintaining, upgrading and expanding physical assets effectively throughout their lifecycle.*" It helps strategic allocation of the resources and decision-making in an optimized and cost effective way using a performance based approach (AASHTO, 2013).

Transportation Asset Management (TAM) helps to quantify the current performance and forecast the future performance with the policies defined and the decisions associated with the planning. With the restricted funding level, TAM helps to determine the effectiveness of decision to achieve the desired level of service of assets. It helps to evaluate the probable consequences of alternative decisions. TAM has a long term vision for asset performance by using an effective maintenance activity involving a small, regular expenditure to delay or postpone a future much larger necessary expenditure (AASTHO TAM Guide, 2011).

Trade-off is an important tool in transportation asset management when there is a need of comparing the effect of two different performance measures. Prioritization and trade-off analysis are directly linked to the resource allocation in transportation asset management. NCHRP Report 551 (2006) describes the core principles of TAM that are used to set the performance measuring criteria as follows:

- **Policy Driven –** Well defined set of policy goals and objectives govern the resource allocation decisions.
- **Performance Based –** System performance is measured from policy objectives that are used for both day-to-day and strategic management.
- **Analysis of Options and Trade-offs –** Decisions on how to allocate resources within and across different assets are based on how the allocation will affect the overall policy objectives.
- **Decisions Based on Quality Information -** The different options are analyzed with respect to the agency's policy goals with a credible and current data.
- **Monitoring to Provide Clear Accountability and Feedback –** Performance results are monitored and evaluated for effectiveness. Feedback on the actual performance may affect the agency's goals and objectives which could influence future resource allocation and decisions.

Project level prioritization is an important aspect of transportation asset management when there is a need of maintaining multiple assets within a project in an acceptable condition with budget constraints. Engineering experience and judgment alone is not efficient enough to manage a large number of projects which need to undergo maintenance and rehabilitation. With limited funds and a large number of projects to analyze, an effective decision support tool which can incorporate the major highway assets in a project is essential for the highway agencies.

Asset performance measures are defined by multiple objectives that show the importance of the asset. Therefore, a method to determine the project index that will use the data-driven results rather than the subjective evaluation alone is needed for a transparent decision. Many researchers have proposed different methods to assist decision makers in resource allocation and ranking of the projects. A review of the existing literature on transportation asset management and various decision support tools used in project level prioritization and the trade-off is explained in Chapter 2.

1.2 Problem Statement

Project prioritization is performed through the trade-off analysis between a set of competing objectives for the project assets. The performance of the transportation system is not evaluated on the basis of the single asset type like pavement or bridge alone. Any transportation project may comprise of asset types like pavement, bridge, culvert, traffic signs & signal structures and many other small assets. Therefore, along with the evaluation of performance measures of the asset types, there is a need for a method to come up with a single index showing the weight or importance of the project as a whole. Trade-off between the competing projects is performed based on multiple criteria used as competing needs a project. Trade-off analysis has an important role in transportation asset management where there is a constraint budget environment.

For the prioritization of projects within the work plan for their effective preservation, decision support tools are needed. In the continuing process of developing the decision support tools for transportation asset management, a trade-off analysis is needed for prioritizing and ranking the individual projects. This comparison assists in the identification of the more important projects in the list of candidate projects. Thus, the research focuses on developing a method to prioritize the projects involving either pavement, bridge or both assets. The process utilizes the currently available data which meets the objectives in the project selection criteria.

1.3 Objective of Study

This research focuses on developing a data-driven project level Trade-off tool which would help in more transparent decisions in prioritizing the rehabilitation projects planned in the work plan. The primary objectives of the study are:

1. To review existing literature in decision support tools and prioritizing techniques used.
2. To use the Analytical Hierarchy Process (AHP) to calculate the relative importance of multiple objectives or criteria.

3. To develop a web based decision support tool using Microsoft Visual Basic.NET (2015) and SQL Server to perform a project level trade-off.

Chapter 2

Literature Review

2.1 Trade-off Analysis

The trade-off is a phenomena or process which involves losing a quality or aspect of something in return for gaining another quality or aspect. Many researchers have used trade-off analysis for the decision-making process, although it is a relatively newer term in transportation asset management.

El-Rayes & Kandil 2005 presented a model to transform a traditional time-cost trade-off analysis to a three-dimensional time-cost-quality trade-off analysis. The model used a genetic algorithm to include quality in construction optimization in the highway construction. Gharaibeh et al. 2006 presented a methodology to allocate funds across different transportation assets performing a trade-off analysis among assets by shifting funds from one class to another. Similarly, Senouci & El-Rayes 2009 developed a multi-objective optimization model to assist the construction resource utilization and to schedule plans simultaneously to minimize the time and maximize the profit of the projects. A trade-off between construction time and profit is performed during the optimization process to find an optimal time and profit.

Bai et al. 2008, investigated the trade-offs between the program areas, performance measures, budget levels, risk and performance thresholds. The dimension unit calculated from the scaling of the performance measures is combined to find a single value that will define the overall importance of the project. The report also describes the method of investigating the trade-offs by changing the performance threshold and shifting of the budgets from one area to another.

Bai et al. 2012, described the methods for trade-off analysis for the multiobjective optimization for transportation asset management. The multiple objectives are interpreted in terms of network level performance measures for the trade-off. The trade-off between performance objectives and the cost is illustrated by the extreme points non-dominated sorting genetic algorithm II (NSGA II) technique. The technique is found to have a faster convergence speed and superior to the traditional methods.

2.2 Decision Support Tools

There are many mathematical models and methods developed in the asset management field for the project selection purposes, resource allocation or ranking of the projects or alternatives in the past. Some of the common decision-making tools for the project selection are as follows:

(i) Multi-attribute Utility Theory (MAUT)

When there are multiple criteria involved, multi-attribute utility theory is an efficient method to rank the alternatives. Edwards (1954) described the theory of decision-making using a reference of Neumann & Morgenstern (1947) which talks about uncertainty and risk associated with the choice of alternatives. MAUT combines the measurement models and scaling techniques for the evaluation of alternatives having multiple attributes (Von Winterfeldt & Fischer 1975). A unique categorization of the health status of individuals two years or older with a four attribute health state classification system using a multi attribute utility theory was presented in Torrance et al. (1982).

Huber (1974) described steps for implementing an approach to estimate the MAUT model parameters. The research helped to validate the use of subjective values that are used as input parameters in the multi-attribute utility functions. The values from the utility functions have a relative meaning with each other (Neufville 1990). The simple additive model in the multi-attribute utility function is expressed as:

$$U(X) = \sum w_i U(X_i)$$

where w_i are scaling factors or relative weight between the different parameters.

MAUT has a great application in material selection where the composition of materials along with it costs and weight is optimized with the utility values (Neufville 1990). MAUT has been used in many transportation asset management systems involving risk and uncertainties (Li & Sinha 2004; Patidar 2007; Rashid & Herabat 2008; Bai et al. 2013). O'har (2011) used MAUT to assist in decision-making for the ranking process which is used in bridge investment. Wang (2014) used MAUT along with the analytic hierarchy process in developing project selection models to generate work plans. Gharaibeh et al. (2006) developed multi-attribute utility function to allocate funds across transportation infrastructure assets which could be used for the trade-off analysis for shifting funds from one asset to another.

(ii) Goal programming

Goal programming is a generalization of the linear programming method to solve the problems with multiple objectives and conflicting goals. The origin of the goal programming method is from Charnes et al. (1955) which describes the compensation methods by linear programming. Charnes & Cooper (1961) first used the term goal programming when the linear programming was extended to apply in the industrial field. Goal programming is a popular and widely used multi-criteria decision-making tool (Romero 2014).

Goal programming has been used in many asset management systems. The main advantage of goal programming is its easy implementation with its simple concept and the fact that it apprehends the essential elements of the problem before converting into goals and constraints (Wu 2008). Ravirala & Grivas (1995) used goal programming methodology to integrate decisions involving pavements and bridge management system. Wu et al. (2012) described the application of the multi-objective optimization on various working levels of the transportation asset management.

(iii) Analytic hierarchy process (AHP)

AHP is a decision-making tool developed by Thomas L. Saaty in 1980 which uses a subjective way of analyzing the decision problem by identifying the various criteria that define the very condition, performing their pairwise comparison, and weighing them to rank different alternative solutions (Saaty 1980).

Ramadhan et al. (1999) described the calculation of the weight of the pavement maintenance priority ranking factors with the use of AHP. The priority factor weights ultimately were used in pavement maintenance priority ranking validated by real case studies. The weights for the factors were calculated with the perception of the different group of individuals locally. The results were compared with the results obtained from procedures used at that time. Two case studies where the road network needed urgent maintenance were selected and the results from the engineering judgment and the one from the developed method were compared which gave statistical non-parametric Spearman rank correlation coefficient as 0.77 and 0.95, respectively. Thus the method was seen to be handy for the projects involving a large number of pavement sections.

Dabous & Alkass (2008) used AHP for the decision support tool to select bridge rehabilitation strategy and validated its results with a case study. It proposed a modified AHP method which considers multiple conflicting criteria along with the traditional life cycle cost in the bridge management for the decision-making purpose. The comparative judgments in the same level in the hierarchy is done by using a pessimistic, most likely and optimistic values for the pairwise comparison. For example, for criteria having weak importance over other, the pessimistic value of 2.5 and optimistic value of 3.5 could be used for a weakly importance value 3.

For the case study to validate the proposed method in the Dabous & Alkass (2008), the Jacques Cartier Bridge in Montreal, Canada was selected which was a major rehabilitation project. The three level of hierarchy was formed to apply the modified AHP to select the alternative rehabilitation strategies. The first level is the goal of the ranking process, the second level is the pairwise comparison of the evaluation criteria and third level being the selection of available rehabilitation strategies. A consistency check is done by the Monte Carlo simulation. The result from the method matched the original decision to replace the bridge deck.

Farhan & Fwa (2009) studied the use of AHP in prioritizing the relative pavement maintenance activities with single pavement distress type. As there is more than one distress type for pavements, Farhan & Fwa (2011) used the AHP for the relative priority of pavement section with multiple distress types. To show a large number of comparisons and decision level involved due to the multiple distresses, a numerical example is presented and compared with the PAVER method to study the results. To perform the AHP, a prioritization questionnaire was prepared requiring a subjective assessment of highway engineers and decision makers. The validity of the results was compared against the direct assessment method in Fwa et al. (1989) by letting five engineers do the direct assessment of the priority ratings of the alternatives. A strong positive correlation was obtained between the results of the AHP and the PAVER method and the direct assessment method which were statistically consistent at 95% confidence level.

Gurganus & Gharaibeh (2012) proposed a method for the project selection of preservation projects using the AHP as the decision-making tool which helps agencies justify the use of funds. It uses a structured decision-making process which helps to select the variables, justify the project prioritization decision and provide a tool for decision-making. For the project selection process, the parameters associated with the preservation are identified, and the data available in the pavement management system is used to select the projects. The hierarchy of the project selection is classified into three levels: (i) Project selection number where the project managers can assess each section with the weight of the decision parameter, (ii) decision parameter level where the various parameters are compared to get the individual weights of the parameters and (iii) section vs. section level where sections are compared with each other to evaluate its importance than other sections.

Gurganus & Gharaibeh (2012) proposed to bridge the gap between network level and project level pavement management by evaluating the preservation projects selected and comparing them with the actual ones. The project ranking by this method at District level matched 75% of the district decisions. Thus a combination of quantitative and qualitative variables describes a decision support tool which helps prioritization of project selection. A room for benefit cost analysis is left where treatment cost of the projects could be added as a decision parameter.

Gonzalez et al. (2013) developed a web based tool using AHP to prioritize the routine maintenance projects and also selecting the maintenance programs and strategies that would help engineers minimize the impact of budget fluctuations in the roadway network condition. The web tool developed uses four pilot districts as a reference for calculating the overall relative weight of the maintenance projects in each individual district or the state average can be calculated. For the individual district, the one from the four pilot districts was chosen that had the closest demographic and climatic region in Texas. This approach helps to schedule and prioritize the maintenance activities for each district by minimizing the risks from budget variations each year.

2.3 Project Prioritization

There have been various studies and progress towards transportation asset management by various researchers. Chen et al. (1996) presented a network level optimization model which provides separate routine maintenance models for each type of pavement. Similarly, Ravirala et al. (1996) have developed a multi-criteria optimization method for the analysis of funding allocation for the bridge infrastructure management using goal programming. Lounis (2005) used multiple objectives for a network level bridge maintenance to prioritize the bridge structures for maintenance. Bridge condition rating, maintenance cost, and traffic flow are used as conflicting objectives for bridge prioritization in Lounis (2005). Abaza (2007) developed global network optimization models for the pavement management system which generates a pavement repair plan. These asset management systems are helpful to develop more robust systems in the present conditions. The asset management systems developed in the past mostly assist in the management of individual asset rather than multiple assets (Wang, 2014).

Rashid & Herabat (2008) describes the role of facilities other than pavement in the highway network by developing a prioritization framework for their maintenance. Multi-attribute utility functions were developed in the process after collecting the experts' opinion and the best-fitted utility function was selected using the linear and nonlinear regression analysis. The higher the utility value, the higher the rank in the priority. The various research has been done in the field of asset management, and the method being already applied in most of the transportation agencies helps to develop a decision support tool for the prioritization of the projects having the multi-assets of a highway.

Most of the state DOTs have been using various decision support tools for the asset management purpose. Montana DOT Transportation Asset Management Plan (2015) describes a Performance Programming Process (P3) for the asset management for the funding allocation and investment plan based on system performance objectives. Risk management and performance gap assessment help in decision-making for both pavement and bridge assets.

California DOT (2016) have developed a prioritization model to prioritize the projects under a program called State Highway Operation and Protection Program (SHOPP). The model uses quantitative data where the decisions are based on the data-driven values and costs. The prioritization of the projects is done using a multi-attribute value theory (MAVT). A linear additive multi-attribute value function using the weights for the different objectives is used to combine the products of weighted values to determine the overall weight of the project. The projects are further analyzed for their sensitivity to changes which gives further insights into the decision-making process.

Project selection level proposed by Gurganus & Gharaibeh (2012) described the use of AHP to incorporate multiple selection parameters ultimately giving the ranking of pavement sections. This study describes the process of project level prioritization. Project level transportation asset management is carried out after the project selection level. Project level comprises of multiple assets unlike in project selection level where different sections in a single asset type like pavement are compared. Within a single project, there can be multiple pavement sections and multiple bridges too. Therefore, a project level prioritization involves the calculation of average criteria weight of all the assets in the project which ultimately gives the project index used to rank a large number of projects. The project level prioritization process is described in Chapter 3.

Chapter 3

Methodology

3.1 Introduction

Project level trade-off can be considered as a prioritization of different projects based on a set of competing objectives. This chapter describes the approach used to develop the project level prioritization with multiple objectives. A multi-objective decision-making methodology called Analytical Hierarchy Process (AHP) as described in the previous chapter is employed to determine the relative weights of different objectives for pavement and bridge separately and ultimately a combined weight is determined for each project for ranking of the projects. The decision support tool thus developed uses a data driven approach supported by qualitative comparison using AHP which helps decision makers justify their work plan.

The ODOT work plan consists of the projects having pavement sections and bridges as the main assets. Some projects have only pavement sections or only bridges for rehabilitation whereas other projects have both pavement and bridges. The average priority weight values of the objectives or criteria from all the pavement sections or individual bridge in a particular project is calculated first, and it is used to calculate the asset priority weight.

Table 3.1 Project from the work plan for Year 2017 in District 2

No.	Year	PID	NLFID	Blog	Elog	SFN	System	Priority
1	2017	92130	SHENSR00065**C	17.09	20.19	NULL	SR	G
2	2017	92130	SHENSR00065**C	17.27	NULL	3502007	SR	G
3	2017	92130	SHENSR00065**C	18.28	NULL	3502023	SR	G
4	2017	92130	SHENUS00006**C	17.81	27.99	NULL	US	G
5	2017	92130	SHENUS00006**C	20.72	NULL	3500691	US	G
6	2017	92130	SHENUS00006**C	21.82	NULL	3500721	US	G
7	2017	92130	SHENUS00006**C	25.21	NULL	3500764	US	G
8	2017	92130	SHENUS00006**C	27.83	NULL	3500780	US	G

Table 3.1 shows a work plan project (PID= 92130) in district 2 for Fiscal Year 2017. The project has 6 bridges and 2 pavement sections from different roadway segments. SFN (Structure File Number) represents the bridge. The NULL values in the Structure File Number (SFN) shows that it is a pavement section. The length of the pavement section is the difference between Elog and Blog which gives us the lane miles. All the pavement sections falling between the Blog and Elog value for each row of a project in the work plan for the unique NLFID is selected and the weighted average value for various pavement parameters like PCR and traffic data is calculated. NLFID is a unique ID showing a route in a county for a system of the roadway. Finally, a weighted average value from all the average values for a project is calculated.

Similarly, for multiple bridges in a project, the average general appraisal for the bridge is calculated from the ODOT bridge inventory data using the unique Structure File Number (SFN) of the bridge. The traffic data is extracted using the Blog and NLFID for the bridge where the traffic data for the roadway section containing the bridge is used as the bridge traffic data. A project can have pavement sections and bridges from a different county or with a different system or priority value. Hence, the prioritization may be carried out only at a District level and for a specific year or for all years. A criteria average table consisting all the average values of the criteria for a pavement and bridge is thus generated. Whenever there is a change in the work plan, this table needs to be regenerated for the web tool using the windows application.

3.2 Analytical Hierarchy Process

Analytical Hierarchy Process helps in finding a comprehensive and rational decision in complex situations involving multi-criteria through pairwise comparison of the criteria. AHP has an advantage of quantifying an element of the problem by their weight. So, it has been widely used in different fields with its ability to solve complex decision-making problems.

AHP can be applied in different decision situations. Some of the situations where the decision-making is a tough task are:

- Choice among a set of alternatives where there are multiple criteria involved.
- Prioritization of a set of alternatives by a merit based ranking.
- Resource allocation among a set of alternatives according to their importance.

The use of AHP though, is not limited only to the situations listed above.

Modeling of any problem using analytic hierarchy process consists of forming a hierarchy structure showing the overall goal of the problem, the factors or criteria which are important to achieve that goal, and a list of alternative solutions to achieve that goal. The criteria or the factors can be further divided into sub-criteria and sub-factors, sub-sub-criteria and so on, depending on how deep the analysis of the problem we require.

The criteria values are classified as a graded difference intensities of criteria. The intensities like high, medium, and low are compared to calculate the weight of each level of intensity under the parent criterion. For example, the surface roughness of the road could be used as an example to describe the intensity level. Smooth road surface is preferred by a driver for comfort and less travel time whereas a rough road surface creates a discomfort to the driver and the passengers along with an increased travel time. Similarly, a pavement section with a good PCR value of 85 will have less weight than the pavement section with fair PCR value of 75. Further, a low PCR value of 60 will have the higher weight than the fair value for its importance to undergo rehabilitation. The number of intensity levels can be formed as per requirement.

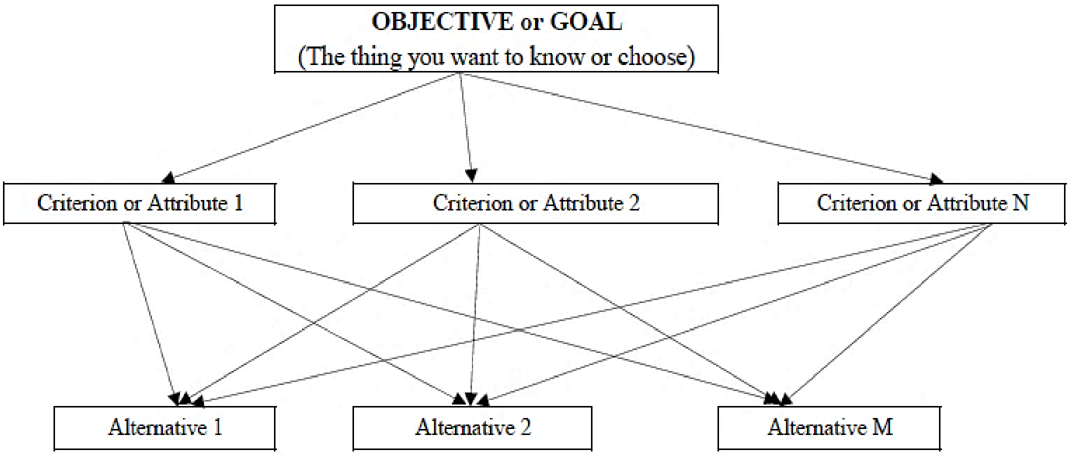

Figure 3-1 Hierarchy showing the comparisons performed for AHP method

Formation of the hierarchy is not a simple task. It involves a significant research, discussion, and availability of data for the criteria to be chosen. The hierarchy can be modified or changed to add a new thought or relevant criteria with newly available data for it. The existing criteria can also be modified and the alternative solutions can be changed as per the research needs.

The relative importance of each criterion compared to other criteria involved is calculated using a pairwise comparison. A criteria comparison matrix is thus formed in the process. Further, each alternative in the hierarchy is compared with other alternatives using one criterion at a time using the pairwise comparison too. This comparison forms an alternative comparison matrix. There is one alternative comparison matrix for each criterion. The relative weights are calculated by multiplying the matrix by itself followed by summing up the resulting elements of rows to get a vector. The resulting vector is obtained by dividing each element by the sum of column elements to obtain the final Eigen vectors. The elements in the Eigen vectors are the relative weights of the corresponding criteria.

The pairwise comparison involves a scale of numbers from 1-9 which gives the relative importance of two criteria in the comparison. Table 3.2 shows the fundamental scale for the pairwise comparison.

Table 3.2 Fundamental Scale for Pairwise Comparison

Intensity of Weight	Importance	Description
1	Equally important	Two activities contribute equally to the objective
3	Slightly more important	Experience and judgment slightly favor one activity over another
5	Moderately more important	Experience and judgment strongly favor one activity over another
7	Strongly more important	Experience and judgment very strongly favor one activity over another
9	Extremely more important	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When there is a dilemma for the judgment between two levels of importance
Reciprocals	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	Same explanation but with the less importance

The above scale and the method of AHP can be elaborated further through an example. For comparing n number of criteria, we get an n x n criteria comparison matrix. For example, when there are four criteria: C1, C2, C3 and C4, a 4 x 4 matrix is formed. Equation 1 shows the generalized 4x4 matrix showing the criteria comparison.

$$\begin{array}{cc} & \begin{array}{cccc} C1 & C2 & C3 & C4 \end{array} \\ \begin{array}{c} C1 \\ C2 \\ C3 \\ C4 \end{array} & \begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} \\ a_{21} & 1 & a_{23} & a_{24} \\ a_{31} & a_{32} & 1 & a_{34} \\ a_{41} & a_{42} & a_{43} & 1 \end{bmatrix} \end{array} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

(4 x 4) matrix where $a_{ij} = 1$ for $i = j$

and $a_{ij} = 1/a_{ji}$ for $i \neq j$

For example, to know the weights for the 3 different intensities: Good (G), Fair (F) and Poor (P) under the parent criterion pavement condition. For the pavement condition, the worse the condition is, the more important is the rehabilitation of that pavement section. Consider, for the pavement condition criteria: Poor condition is moderately more important than fair condition and extremely more important than good condition for its maintenance priority. Similarly, say the fair condition is strongly more important than good condition. This criteria intensity comparison forms a 3x3 matrix to give the relative weight of each intensity.

$$\begin{array}{cc} & \begin{array}{ccc} G & F & P \end{array} \\ \begin{array}{c} G \\ F \\ P \end{array} & \begin{bmatrix} 1 & 1/7 & 1/9 \\ 7 & 1 & 1/5 \\ 9 & 5 & 1 \end{bmatrix} \end{array} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Self-multiplication of the comparison matrix gives a resulting matrix. The sum of elements in each row from the resulting matrix when divided by the total sum of all the elements gives the relative weight of criteria required.

Table 3.3 Calculation of relative weight

	Good	Fair	Poor	Sum	Weight
Good	3.00	0.84	0.25	4.09	**0.04**
Fair	15.80	3.00	1.18	19.98	**0.22**
Poor	53.00	11.29	3.00	67.29	**0.74**
			Sum	138.26	1.00

Similarly, an alternative comparison matrix for each criterion is formed to get the relative weight of each alternative with respect to that criterion. If the decision problem has N number of criteria and M number of alternatives, then we would get an N x N criteria comparison matrix and N number of M x M alternative comparison matrices.

3.3 Project Level Trade-off Analysis

Project Level Trade-off analysis can be considered as prioritization of different projects based on competing criteria in different assets. This method describes an approach to develop the project level prioritization tool for the criteria based ranking of the projects involving multiple assets. Analytical Hierarchy Process (AHP) is employed to determine the relative weights of the different objectives for pavement and bridge assets. Ultimately, a combined weight which is a project index for the multi-asset project is determined for each project. The project index is used for the ranking of projects.

This process uses the criteria comparison method in the AHP to get importance or weight of various assets. Unlike the core application of AHP, it does not undergo the comparison of the alternatives but merely ranking them. The project level Trade-off analysis uses available data for various project selection criteria. The various tables in the database used for the calculations along with their description are listed in Table 3.4 below.

Table 3.4 Tables used for calculations in the web tool

Table	Use	Remarks
Pavement Inventory Table	Used for extracting the pavement condition data for the pavement sections in work plan.	DATA_ODOT, Lookup table
Bridge Inventory Table	Used for extracting the bridge data for the bridges in the work plan	Bridge_2016, Lookup Table
Work plan	Used as the primary table for analysis and prioritization of the projects in it.	Work_Plan, project list
Criteria Average Table	Used in the web tool for the average values of various criteria in individual project (PID)	Criteria_Average, Generated with windows application
Distress Type Table	Used to define the values for importance of rutting with severity and extent multipliers	LU_Distress, Defined from ODOT

The AHP methodology uses a pairwise comparison to determine the relative weights of each objective as described in the previous section of this chapter. The more important object will have a higher weight. Given there are n objectives, the total number of pairwise comparison will be $\frac{n!}{2(n-2)!}$.

For a pavement asset, the following four objectives are considered in a rehabilitation project:

(1) Asset Preservation,

(2) Congestion Mitigation,

(3) Safety Improvement, and

(4) Economic development.

Hence, for the four objectives in a pavement asset, the number of pairwise comparisons will be $\frac{4!}{2(4-2)!} = 6$. Figure 3-2 shows the sliders that are used for comparison of the objectives.

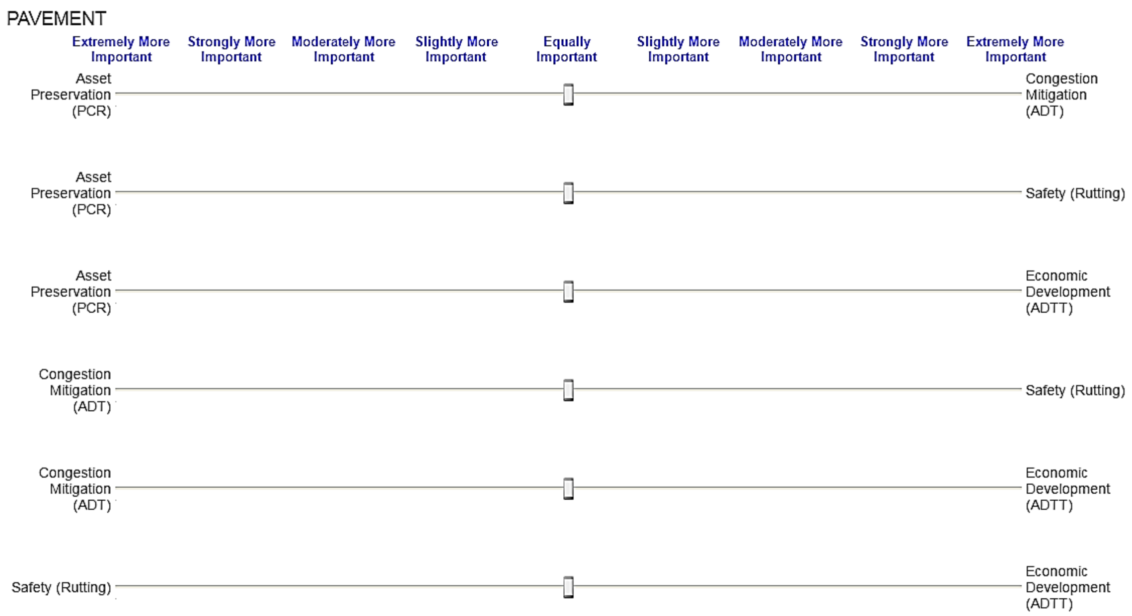

Figure 3-2 Pairwise comparison of the pavement weight objectives

The pairwise comparison for the pavement asset above is performed with the slider position indicating the importance of one objective over another. The slider is composed of levels of importance of one objective over another along with the intermediate levels between them. One objective can be equally important (1), slightly more important (3), moderately more important (5), strongly more important (7) and extremely more important (9) than the other. The slider value between slightly more important and moderately more important is 4 which is an intermediate level.

1. Asset Preservation

The asset preservation objective in pavement asset is described by Pavement Condition Rating (PCR) which is calculated from the type of distress in the pavement section and their severity & extent. For the asset preservation, it is assumed that pavements in poorer condition (i.e. with lower PCR scores) should be “preserved” (i.e. rehabilitated) sooner so that these pavements would not deteriorate further into very poor or failed condition, which would require very costly reconstruction. Therefore, PCR, which is an indicator of pavement condition, is used as a numerical criterion for the pavement preservation objective.

ODOT has a manual for the rating of pavement condition. The mathematical form expressing the PCR value is as follow:

$$PCR = 100 - \sum_{i=1}^{n} D_i$$

where, D_i = Deduction for distress type

n = Number of distresses

The deduction is calculated by multiplying the assigned weights for distress type, distress severity, and distress extent. There are various types of distresses which are assigned a certain weight according to their effect on the pavement condition. The severity is further classified into high, medium, and low. Similarly, the extent of distress is classified as occasional, frequent, and extensive. These parameters are monitored carefully in order to calculate a worthwhile rating for the pavement condition.

PCR having the value ranging from 0 to 100, are divided into three levels: Good (80-100), Fair (66-79) and Poor (0-65). The PCR value used for the particular project is the weighted average PCR for the segments of roads in any project. For example: if any project has three segments of roads as follows:

Segment	Length (miles)	PCR
1	3.83	63
2	0.75	90
3	6.30	72

Weighted Average PCR = (3.83 x 63 + 0.75 x 90 + 6.30 x 72) / (3.83+0.75+6.3)

= 70.07

Hence, the average PCR for the pavement in the project will be 70.

2. Congestion Mitigation

Traffic congestion is a phenomenon occurred either by a recurring incident caused by increased use of the road or a non-recurring incident like weather conditions, accidents or constructions resulting in queuing of the vehicles. It is assumed that mitigating traffic congestion is also an objective of any pavement rehabilitation project. The high traffic volume implies that a large number of people rely on the infrastructure they use for commuting. A pavement rehabilitation project improves the ride quality and often involves widening. Therefore, routes with higher traffic volume (i.e. higher average daily traffic (ADT)) would benefit more from a pavement rehabilitation than routes with fewer ADT. Thus, it is important for the government to give priority to the assets which are exploited mostly. The Average Daily Traffic (ADT) is the traffic data which is used for the congestion mitigation objective.

Congestion mitigation by building more roads and infrastructure is very costly and not environment-friendly. Thus, scheduling maintenance for the assets to at least ease off the heavy congestion due to the traffic volume makes it an important aspect in prioritizing the projects. During the AHP, pavement sections having a high traffic is assigned a higher weight, and lower traffic is assigned a lower weight. This makes a rational analysis of the projects according to the traffic condition they have and help address the most congested highway locations to save user costs associated with delays. ADT in this study is divided into three different level of volume: High (>5000), Medium (1000-5000) and Low (0-999).

The average traffic volume in the project is calculated as the weighted average ADT similar to the calculation of average PCR.

3. Safety Improvement

Safety improvement objective in the pavement assets is described by the distress type rutting. Rutting is the vertical deformation of the pavement surface along the wheel tracks where a depression is noticeable (ODOT PCR Manual, 2006). It is measured in terms of the rut depth. The severity and extent of the rut are classified by Ohio DOT's PCR manual as listed in Table 3.5. Chan et al. (2010) showed that the rutting has a significant role in accidents during nights and under rain conditions. With an average annual precipitation as high about 38 inches (Ohio Dept. of Natural Resources) in the state, rutting seems to be an important factor to be considered for the safety in roadways in Ohio. The pavement rutting value ranges from 0 to 10 according to the importance of rutting in the distress type, severity of rutting and extent of rutting.

Table 3.5 Range of severity and extent of rutting with their multiplier value

Severity	Range	Severity Multiplier	Extent	Range	Extent Multiplier
Low	1/8" – 3/8"	0.3	Occasional	<20%	0.6
Medium	3/8" – 3/4"	0.7	Frequent	20-50%	0.8
High	> 3/4"	1	Extreme	>50%	1

The rutting value is calculated by multiplying the distress type weight of rutting with the multiplier of severity and multiplier of the extent of rutting. Distress type weight for rutting is assigned as 10 by ODOT. For example, consider a pavement section having a rutting of medium severity with frequent extent.

Rutting = Distress type weight x Severity multiplier x Extent multiplier

= 10 x 0.7 x 0.8

= 5.6

In this study, rutting is divided into two levels: Acceptable (≤ 5) and Not Acceptable (>5). The average rut is calculated similarly to the calculation of average PCR where a weighted average value is used. Therefore, pavement with the unacceptably high level of rutting should be rehabilitated to meet the safety improvement objective.

4. Economic Development

The economic development of the state or the nation is very much dependent on the transportation network especially in the freight network through trucks. Trucks play a major role in the movement of goods which ultimately play a major role in the economic development. Ohio is a major crossroad state for the freight movement. Almost 43% of the total freight movement in Ohio is through the state of which 68% of freight movement is truck mode (Ohio Statewide Freight Study, 2013). According to the study in the Ohio Statewide Freight Study in 2013, the truck traffic volume is forecasted to increase about 67 % by 2040 leaving other modes of freight movement relatively the same. This makes the truck traffic, more specifically Average Daily Truck Traffic (ADTT) an important factor in achieving the objective of economic development.

The ADTT in this study is divided into three sub-categories as well. The three levels of truck traffic volume are: High (>750), Medium (75-750) and Low (0-74). The average ADTT for the project is calculated similarly to the calculation of ADT.

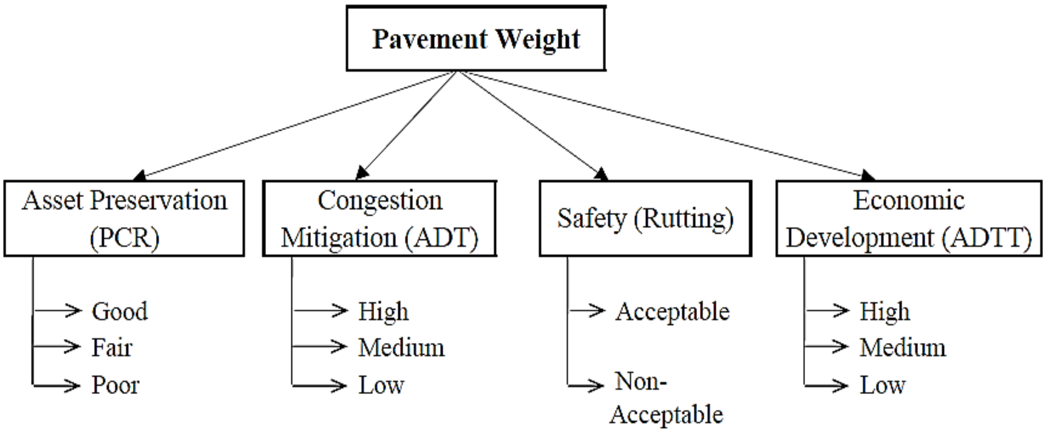

Figure 3-3 Hierarchy for comparison between different pavement objectives

Figure 3-3 shows the pavement weight objectives with their criteria intensities. The range and default weight for the various objective intensities for a pavement section are shown in Table 3.6. The range and the weights for various intensities are assigned from engineering judgment and these weights are used to calculate the pavement weight in a project. However, the user can change the weight in the web tool as per requirement.

Table 3.6 Default Weights for Individual Pavement Section

(a) Asset Preservation Objective

Pavement Asset Condition	PCR Range	Weight
Good	> 80	0.05
Fair	66 ≤ PCR < 80	0.20
Poor	< 66	0.75

(b) Congestion Mitigation Objective

Traffic Volume	ADT Range	Weight
High	> 5,000	0.75
Medium	1,000 – 5,000	0.20
Low	0 – 999	0.05

(c) Safety Improvement Objective

Pavement Rutting	Rutting Distress	Weight
Acceptable	≤ 5	0.20
Not Acceptable	> 5	0.80

(d) Economic Development Objective

Truck Traffic Volume	ADTT Range	Weight
High	> 750	0.75
Medium	75 – 750	0.20
Low	0 – 74	0.05

Similarly, for a bridge asset, we consider the following three objectives in a rehabilitation project:

(1) Asset Preservation,

(2) Congestion Mitigation,

(3) Economic Development.

For the three objectives in a bridge asset, the number of pairwise comparisons will be $\frac{3!}{2(3-2)!} = 3$. Figure 3-4 shows the sliders that are used for comparison of the objectives for bridge asset.

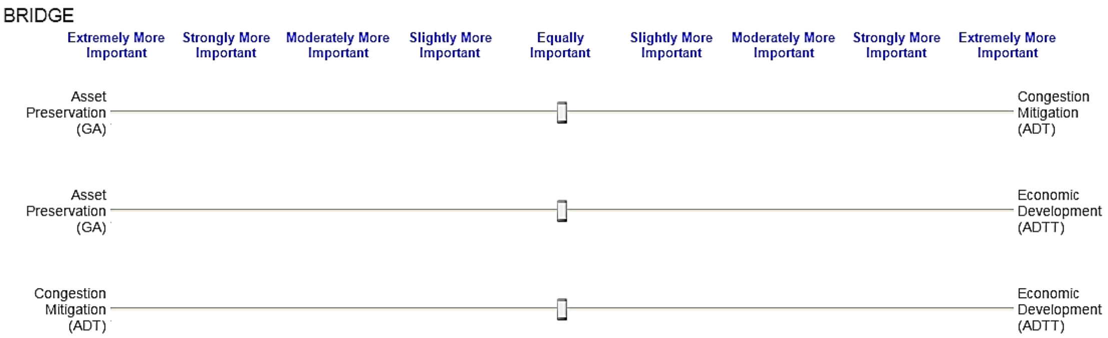

Figure 3-4 Pairwise comparison of the bridge weight objectives

The pairwise comparison for the bridge asset above is performed with the slider position indicating the importance of one objective over another as described earlier in this section.

The description of the objectives in a bridge asset are as follows:

1. Asset Preservation

The Asset preservation in the bridge asset is described by the General Appraisal (GA). General Appraisal shows the condition of structural parts of the bridge such as superstructure, piers, and abutments. It is assumed that the bridges in poorer condition (i.e. with lower General Appraisal value) should be "preserved" (i.e. rehabilitated) sooner so that these bridges would not deteriorate further into very poor or unserviceable condition requiring major rehabilitation or replacement (new construction). ODOT has developed a manual using National Bridge Inspections Standards (NBIS) to undergo bridge inspection for the condition rating of the bridges. Elements of approach items, deck items, substructure items, superstructure items, culvert items, channel items, sign/utility items, and various other supplemental items are inspected and the 9-0 summary rating is prepared for the rating of each bridge condition.

Table 3.7 NBIS Condition Rating Guide

<table>
<tr><th>Condition</th><th colspan="2">9-0 NBIS Summary</th></tr>
<tr><td rowspan="3">GOOD</td><td>9 – Excellent</td><td rowspan="2">No problems noted, newly constructed, general deterioration</td></tr>
<tr><td>8 – Very Good</td></tr>
<tr><td>7 – Good</td><td>Minor problems</td></tr>
<tr><td rowspan="2">FAIR</td><td>6 – Satisfactory</td><td>Minor deterioration in structural elements.</td></tr>
<tr><td>5 – Fair</td><td>Deterioration in structural elements but are sound.</td></tr>
<tr><td rowspan="2">POOR</td><td>4 – Poor</td><td>Advanced deterioration that can be seen with difference between as built and present structural conditions</td></tr>
<tr><td>3 - Serious</td><td>Advanced deterioration with possible local failures.</td></tr>
</table>

CRITICAL	2 – Critical	Serious deterioration, may need to close bridge
	1 – Imminent Failure	Critical, major deterioration, bridge shall be closed.
	0 – Failed	Failure, replacement with new construction needed.

The developed bridge rating is called the General Appraisal which ranges from 0-9 where 0 is the bridge out of service and 9 is the bridge in excellent condition or newly constructed bridge (ODOT Manual of Bridge Inspection, 2014).

Table 3.7 describes the condition rating guide for bridge inspection. ODOT uses these guidelines to rate the bridge condition. The GA values in this study are divided into three levels: Good (≥ 7), Fair (5 - 7) and Poor (<5). The average GA values for the projects having a multiple number of bridges is taken as the average GA value from all bridges in that project. For example, for a project having three bridges as follows:

Bridge	GA
1	6
2	7
3	4

Average GA = (6+7+4) / 3 = 5.7

2. Congestion Mitigation

Congestion mitigation objective in bridge asset is similar to the pavement asset. The bridges having the higher traffic are preferred for maintenance than those bridges having low traffic volume. The average ADT value for the bridge as far as the project consists of pavement sections is same as the ADT for pavement. Whenever there are no pavement sections in the project, average ADT for the project is simply the average traffic volume on the bridges.

3. Economic Development

Economic development objective in bridge asset is similar to the pavement asset as well. The bridges that get more flow of truck traffic are more important for maintenance and rehabilitation than the bridges with low truck traffic. The calculation of average ADTT for the bridge is similar to the calculation of ADT in the bridge as described earlier.

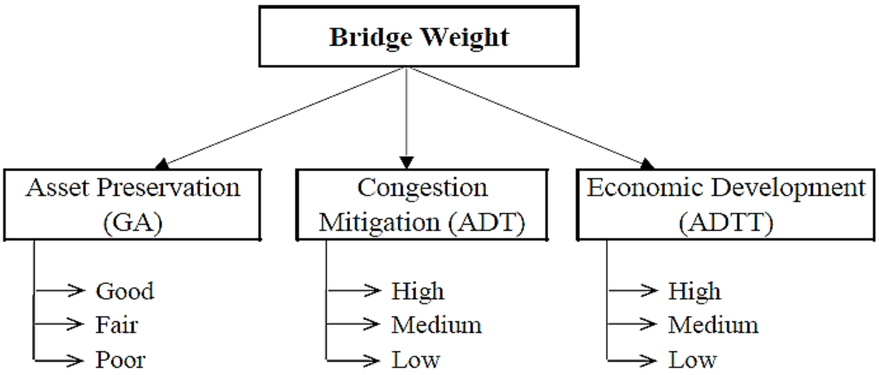

Figure 3-5 Hierarchy for comparison between different bridge objectives

Figure 3-5 shows the bridge weight objectives with their criteria intensities. The range and default weight for the various objectives for an individual bridge are shown in Table 3.8. The range and weights for various intensities are assigned from engineering judgment, and these weights are used to calculate the bridge weight in a project.

Table 3.8 Default Weights for Individual Bridge

(a) Asset Preservation Objective

Bridge Asset Condition	GA Range	Weight
Good	≥ 7	0.05
Fair	$5 \leq GA < 7$	0.20
Poor	< 5	0.75

(b) Congestion Mitigation Objective

Traffic Volume	ADT Range	Weight
High	> 5,000	0.75
Medium	1,000 – 5,000	0.20
Low	0 – 999	0.05

(c) Economic Development Objective

Truck Traffic Volume	ADTT Range	Weight
High	> 750	0.75
Medium	75 – 750	0.20
Low	0 – 74	0.05

Now the Asset weight can be calculated as follow:

Asset Weight = $\sum_{i=1}^{m} C_i * L_i$

where, m = number of criteria for the asset;

C_i = Objective (Criteria) weight for criteria i from AHP

L_i = Criteria condition or level weight for criteria i (default weight)

3.4 Implementation

The project-level trade-off tool is developed using Microsoft Visual basic.NET (2015) framework and the SQL Server. The ODOT database for the pavement and bridge is used in the analysis of results. The project level prioritization process has four parts: database, data selection & preparation, trade-off analysis with AHP, and resulting output. The database part has the data required for the analysis. It contains the work plan which has all the project details needed for the prioritization. It also contains the database table which has the average values of the required criteria for projects listed in the work plan calculated from the pavement and bridge data in ODOT database.

Data selection is the process in which the user is allowed to select the projects from a specific district and year. The user can also change the default weights for the criteria range defined for various objectives. Trade-off analysis with AHP is the pairwise comparison of the objectives or criteria for pavement and bridge weight separately. The resulting output is the ranking of the projects according to the user input for pairwise comparison and the criteria weight for different criteria range provided. The implementation of the whole methodology in the web tool is further described in Appendix A which can also be used as the user manual for Project Level Trade-off Analysis part.

3.5 Sample solution from web tool

A sample solution run from the web tool is discussed in this section. It describes the process of calculating the project weight and ranking of the projects. For example, we want to run the prioritizing tool for all the projects in District 2 for all years in the work plan. The pavement and bridge index criteria or the objectives are set and the district and year for which the prioritization needs to be done are selected.

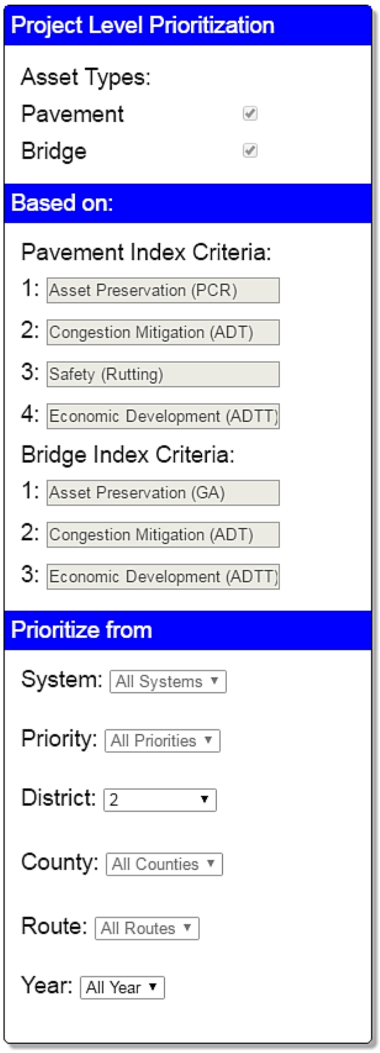

Figure 3-6 Selection of district and year for prioritization of projects

The next step is to perform the pairwise comparison of the criteria in both pavement and bridge assets which gives the objective weight for both assets. Figures 3-7 and 3-8 show the sample pairwise comparison of the objectives performed for the pavement and bridge asset, respectively.

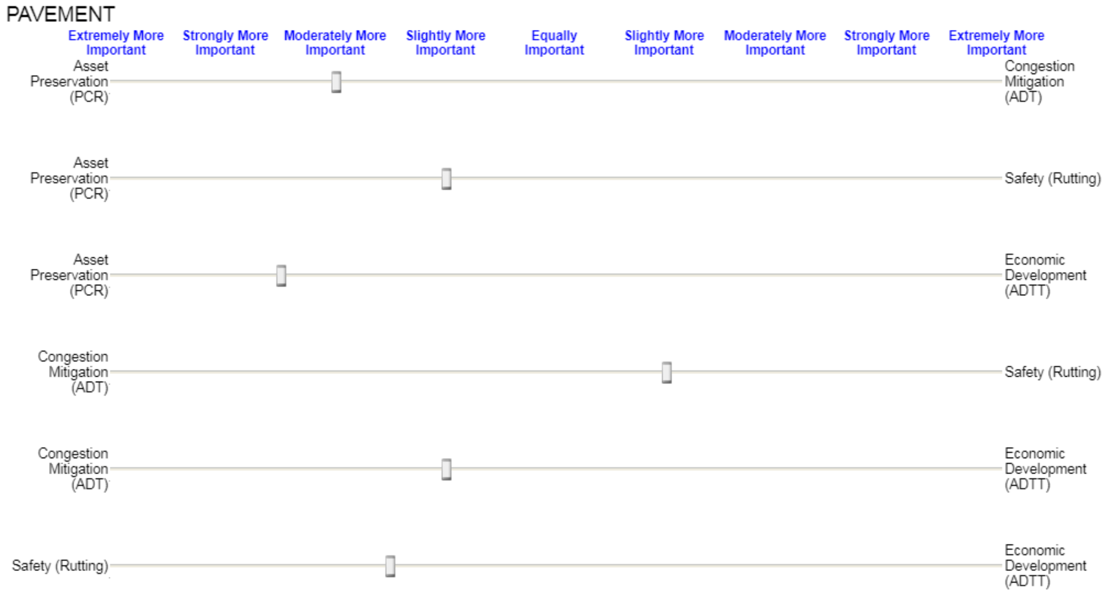

Figure 3-7 Pairwise comparison of objectives for a pavement asset

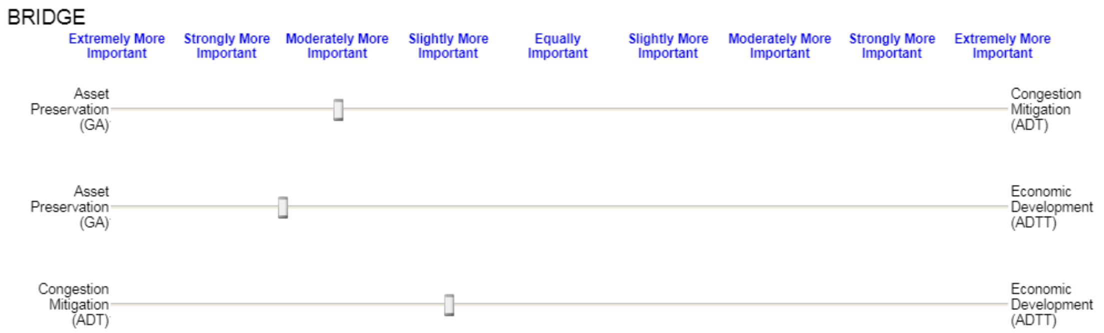

Figure 3-8 Pairwise comparison of objectives for a bridge asset

The comparison for the pavement asset objectives above shows that the asset preservation objective i.e., PCR is moderately more important than the congestion mitigation objective i.e., ADT. Similarly, asset preservation is taken as slightly more important than safety objective (Rutting), and it is between the moderate and strongly more important than economic development objective (ADTT). The safety objective is taken as slightly more important than congestion mitigation objective. Similarly, the safety objective is between slightly and moderately more important than the economic development. The congestion mitigation objective is slightly more important than economic development.

The pairwise comparison performed above between the four objectives for the pavement asset forms a 4x4 matrix:

$$
\begin{array}{cc}
 & \begin{array}{cccc} PCR & ADT & Rutting & ADTT \end{array} \\
\begin{array}{c} PCR \\ ADT \\ Rutting \\ ADTT \end{array} &
\begin{bmatrix}
1 & 5 & 3 & 6 \\
1/5 & 1 & 1/3 & 3 \\
1/3 & 3 & 1 & 4 \\
1/6 & 1/3 & 1/4 & 1
\end{bmatrix}
\end{array}
$$

Multiplying the matrix by itself results in the following matrix:

$$
\begin{array}{cc}
 & \begin{array}{cccc} PCR & ADT & Rutting & ADTT \end{array} \\
\begin{array}{c} PCR \\ ADT \\ Rutting \\ ADTT \end{array} &
\begin{bmatrix}
4 & 21 & 9.17 & 39 \\
1.01 & 4 & 2.02 & 8.53 \\
1.93 & 9 & 4 & 19 \\
0.48 & 2.25 & 1.11 & 4
\end{bmatrix}
\end{array}
$$

Table 3.9 shows the calculations involved in the weight for various pavement objectives. Figure 3-9 shows the relative importance (i.e. weights) chart based on the comparison.

Table 3.9 Weight calculation process for pavement asset objectives

	PCR	ADT	Rutting	ADTT	Sum	Weight	Remarks
PCR	4.00	21.00	9.17	39.00	73.16	73.16/130.50 **= 0.561**	PCR Weight
ADT	1.01	4.00	2.01	8.53	15.56	15.56/130.50 **=0.119**	ADT Weight
Rutting	1.93	9.00	4.00	19.00	33.93	**0.26**	Rut Weight
ADTT	0.48	2.25	1.11	4.00	7.84	**0.06**	ADTT Weight
				Total	**130.50**		

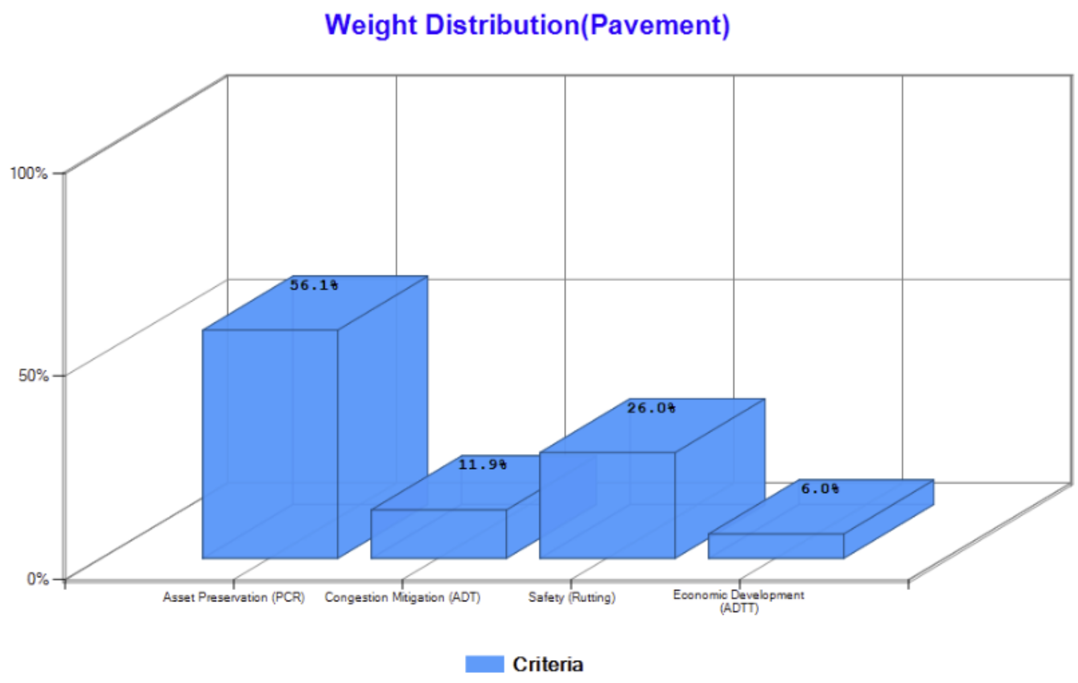

Figure 3-9 Relative weight for each pavement objective calculated by AHP

The comparison of the bridge asset objectives in Figure 3-8 shows that the asset preservation objective i.e., GA is moderately more important than congestion mitigation objective i.e., ADT and it is between moderately and strongly more important than the economic development objective i.e., ADTT. Similarly, the congestion mitigation objective is slightly more important than economic development.

The pairwise comparison performed above between the three objectives for the bridge asset forms a 3x3 matrix:

$$\begin{bmatrix} & GA & ADT & ADTT \\ GA & 1 & 5 & 6 \\ ADT & 1/5 & 1 & 3 \\ ADTT & 1/6 & 1/3 & 1 \end{bmatrix}$$

Multiplying the matrix by itself gives the following matrix:

$$\begin{bmatrix} & GA & ADT & ADTT \\ GA & 3 & 12 & 27 \\ ADT & 0.9 & 3 & 7.2 \\ ADTT & 0.4 & 1.5 & 3 \end{bmatrix}$$

Table 3.10 shows the calculations involved in the weight calculation for various bridge objectives. Figure 3-10 shows the relative importance (i.e. weights) chart based on the comparison.

Table 3.10 Weight calculation process for bridge asset objectives

	GA	ADT	ADTT	Sum	Weight	Remarks
GA	3.00	12.00	27.00	42.00	42.00/58.00 **= 0.724**	GA Weight
ADT	0.90	3.00	7.20	11.10	**0.191**	ADT Weight
ADTT	0.40	1.50	3.00	4.90	**0.084**	ADTT Weight
			Total	**58.00**		

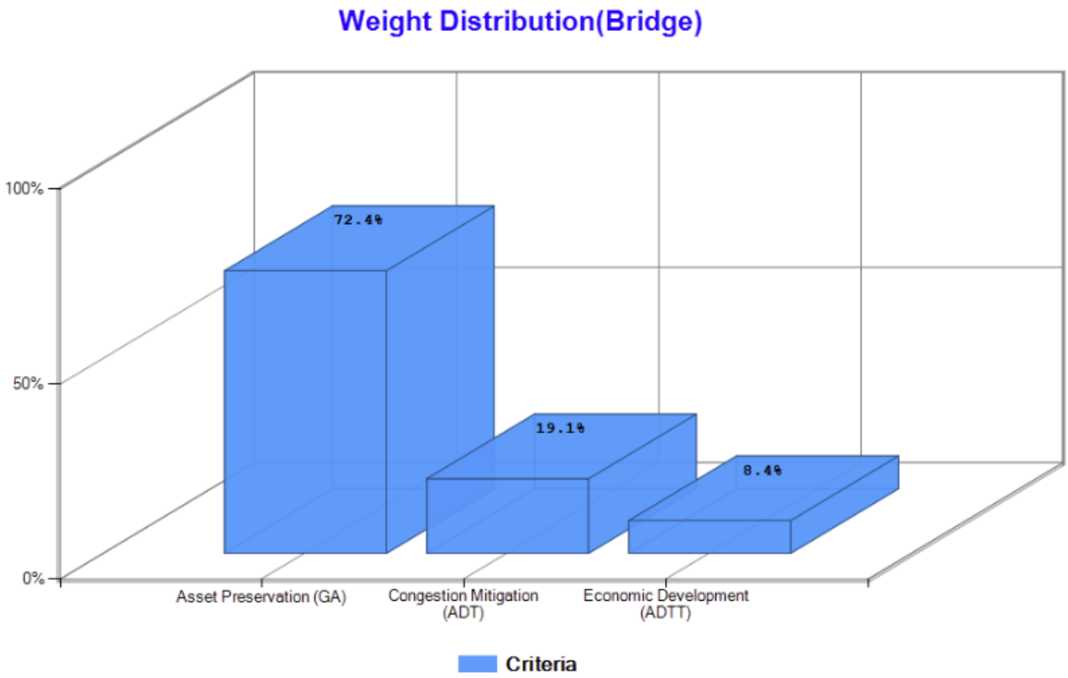

Figure 3-10 Relative weight for each bridge objective calculated by AHP

The next step in the calculation of the overall pavement weight or bridge weight requires the value of the parameters associated with the objectives. The default weights for different criteria in an individual pavement section or a bridge are used to calculate the overall pavement or bridge weight. The default weights can also be modified by the user as per requirement. In this example solution, the default weights are taken for the calculation process.

The sample calculation of the pavement and bridge weight for a PID ‘92127’ is described below. The pavement and bridge asset details in the project are extracted from the work plan. Average PCR, Rutting, GA, ADT, and ADTT for all the projects in the work plan are pre calculated using the details and ODOT data for pavement & bridge.

For any asset, we have

Asset Weight = $\sum_{i=1}^{m} C_i * L_i$

Table 3.11 Sample calculation for the pavement weight

Pavement Objective	Objective Weight (C_i)	Criteria Average	Criteria Weight (L_i)	Total Weight ($C_i * L_i$)
Asset Preservation (PCR)	0.561	60.3	0.75	0.421
Congestion Mitigation (ADT)	0.119	9614	0.75	0.089
Safety (Rutting)	0.26	5.23	0.8	0.208
Economic Development (ADTT)	0.06	1359	0.75	0.045
			Pavement Weight	**0.763**

Here, the low PCR, high rutting, high total traffic, and high truck traffic accounts for the high pavement weight.

Table 3.12 Sample calculation for the bridge weight

Bridge Objective	Objective Weight (C_i)	Criteria Average	Criteria Weight (L_i)	Total Weight (C_i * L_i)
Asset Preservation (GA)	0.724	7	0.05	0.036
Congestion Mitigation (ADT)	0.191	9614	0.75	0.143
Economic Development (ADTT)	0.084	1359	0.75	0.063
			Bridge Weight	**0.242**

Here, the high GA value accounts for the low bridge weight. Since the asset preservation objective has the highest importance, the high value of GA implies the lesser bridge weight.

Table 3.13 shows the results from the prioritization tool for the Top 20 projects ranked out of the 312 different projects in District 2.

Table 3.13 Prioritized project list for District 2

Rank	PID	Year	District	#Bridges	Lane Miles	Avg PCR	Avg Rutting	Avg GA	Avg ADT	Avg ADTT	Pavement Weight	Bridge Weight	Project Weight
1	93918	2016	2	0	6.84	46	5.6	0	12796	802	0.763	0	0.763
2	92127	2016	2	1	19.2	60.3	5.23	7	9614	1359	0.763	0.242	0.763
3	97011	2019	2	0	2.42	61	6	0	12843	903	0.763	0	0.763
4	85266	2018	2	1	0	0	0	4	30990	2060	0	0.749	0.749
5	101327	2020	2	1	0	0	0	4	27911	1879	0	0.749	0.749
6	92095	2015	2	1	0	0	0	4	17807	2347	0	0.749	0.749
7	92331	2016	2	1	0	0	0	4	14930	1011	0	0.749	0.749
8	101556	2019	2	1	0	0	0	4	14930	1011	0	0.749	0.749
9	79901	2021	2	1	0	0	0	4	14350	970	0	0.749	0.749
10	79991	2016	2	3	0	0	0	4.3	47873	4067	0	0.749	0.749
11	85269	2016	2	1	23.62	58.4	6.53	7	6299	561	0.73	0.196	0.73
12	92361	2020	2	0	6.04	65	5.6	0	6010	720	0.73	0	0.73
13	97012	2018	2	2	5.54	63	3.9	4.5	6170	380	0.574	0.703	0.703
14	95792	2021	2	0	20.74	58.6	6.09	0	3288	661	0.665	0	0.665
15	95793	2017	2	1	19.01	60	6.09	6	3497	415	0.665	0.2	0.665
16	101281	2018	2	1	13.78	62	5.49	5	1927	215	0.665	0.2	0.665
17	88513	2015	2	0	5.12	64	5.6	0	3430	560	0.665	0	0.665
18	92128	2019	2	0	12.16	65	6	0	1410	167	0.665	0	0.665
19	84079	2017	2	1	7.58	40	6	5	420	30	0.638	0.159	0.638
20	99869	2018	2	0	1.68	51	4.2	0	25233	1705	0.607	0	0.607

Chapter 4

Results and Discussion

4.1 Results

The result in Table 3.13 shows the objective based prioritized project list from work plan for District 2 with the current data for the pavements and bridges. Most of the projects in the work plan contain both pavement and bridge assets. There could be a single or multiple pavement sections, and/or also multiple bridges in any project. The project ranking is based on the project weight that is calculated from the pavement and bridge weights. The priority weight for the pavement sections is the weighted average priority weight of all the pavement sections in the project. Similarly, average bridge priority weight is the average priority weight of the bridges in that particular project. The overall weight of the project is the higher of the pavement and bridge weights. For the projects having only one of the pavement or bridge asset, the project weight is equal to the asset weight.

Since we are dealing with the asset weight from a range of values for criteria described, many projects may have the same project weight. It is feasible that a project with a PCR 45 has the same weight as a project with PCR 65 which falls within the same range of low PCR. The projects which have the same project weight are further ranked with their PCR values where low PCR gets the higher rank. If the project having only the bridges in it have the same weight, they are ranked according to their GA values with low GA value having the higher weight. If the PCR or GA is also the same, then the project with the higher traffic volume gets the higher rank. As it can be seen in Table 3.13, the Top 3 projects have the same project weight. So, they are ranked according to the PCR value based on the Average PCR. Hence, PID 93918 is ranked first. High rutting value and high traffic volume further justify its ranking here.

Projects ranked from fourth to ninth have the same weight and same GA value. Hence they are further sorted based on their traffic volume (ADT). Similarly, we can see that some of the projects scheduled only after 2018 fall in the Top 5 projects list. Only 7 of the Top 20 projects are scheduled in 2015-2016. This contrasts the decision maker's formulation of the work plan which should include more of these projects in the schedule for maintenance sooner. These results show a support to decision makers to revise or change their work plan considering all the social and economic factors too.

4.2 Discussion

The project level trade-off tool developed here uses multiple assets in a project to find the overall project weight for the prioritization of projects by ranking them. Analytical Hierarchy Process, using both the quantitative and qualitative information, is able to give the user the relative importance between different objectives for project selection. The number of objectives or criteria for the project selection or ranking purpose are chosen wisely to avoid too many pairwise comparisons which is difficult for a user to percept. The trade-off is between the competing objectives where an objective is preferred over another objective and the results can be seen at the various level of importance of one objective over another with a subjective comparison. The default weights for various criteria levels are set to limit the number of pairwise comparisons which is unnecessary. The default weights are chosen with wise engineering knowledge and judgment of the effect, the criteria could have on the objective.

The ranking can be done at a state level comprising of all the projects in the state or in district level where ranking is done for a particular district. The results can also be shown for a particular year. This could help decision makers to select the prioritized projects with the budget level provided in that particular year. For example, if two of the projects scheduled for later years are ranked ahead of one project which is scheduled before them, and have a lesser total combined project cost, the two projects can be scheduled before the single project. However, this decision also depends on various socioeconomic and environmental factors too. Therefore, the basic idea of the decision-making tool is to help decision makers not only choose the projects wisely but also to use the restrained funds effectively.

Chapter 5

Conclusion and Recommendations

5.1 Conclusion

This study describes a data driven approach for a decision support in the project prioritization process. The literature review for the different decision support tools was conducted and the Analytic Hierarchy Process was selected to incorporate both the qualitative and quantitative information for the research. The pairwise comparison based on AHP accompanies both the quantitative and qualitative analysis of the criteria. The tool uses the data from the ODOT database. The AHP method used the decision criteria such as PCR, rutting, ADT, and Truck ADT for the pavement. General Appraisal, ADT and Truck ADT for the bridge were used. The default weights for the criteria value were assigned with a linear scale. Pairwise comparison of the objectives for project selection and the default weights for the objective parameter were entered to calculate the final weight for pavement and bridge. This will help the Districts to better prioritize the projects listed in the work plan. The sample solution and results describe the method which is implemented within a web based prototype ODOT TAM decision support tool.

The basic idea of the project level trade-off is to incorporate the project selection criteria where a trade-off between the criteria is performed. The justification and effectiveness of the limited funds in the transportation agencies highlight the need for the research. However, the consistency and effectiveness of the method rely on the available data quality. The objective of the research to develop a decision support tool using the Analytic Hierarchy Process is met. Some of the important conclusions from the research are as follows:

(i) The development of a trade-off tool in a project level framework incorporates the multiple performance criteria and gives a data driven result which is needed for transparency of project formulation and implementation.

(ii) The consistency and the effectiveness of the tool rely on the quality of information.

(iii) The flexibility of the decision support framework leaves room for editing the future changes or adding new criteria and strategies.

(iv) Analytic Hierarchy Process is a great tool for solving multi-criteria or multi-objective decision-making problems. AHP can utilize the data (quantitative data) and engineering judgment (qualitative data) to give effective results.

(v) The developed decision support tool can rank a large number of projects which is not feasible with engineering judgments that can analyze and deal with just a handful number of projects.

5.2 Recommendations

The method and concept used in this research for the asset management purpose is for the support of decision-making. The factors and objectives used for the decision-making purpose are for a sound and transparent decision. However, the method used here may not be solely used for the final project selection. There are numerous other processes that are required often for the final decision for the project. Sound engineering judgment with respect to the various social and political environment as well as the economic point of view is needed for the final solution.

The objectives or the criteria for calculating the asset weights are from the availability of data to facilitate the data driven and transparent method of ranking the projects. There are various other objectives which could be accommodated for the project selection process with the availability of quality data. The objectives could be related to the environmental impact, quality of service, project cost, and crash rates (safety objective). The change in traffic volume due to new developments going on in the region could also be incorporated in case of commercial areas. These objectives are dependent on the availability of quality data and data collection methods.

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Appendix A

Project Level Trade-off Tool Example

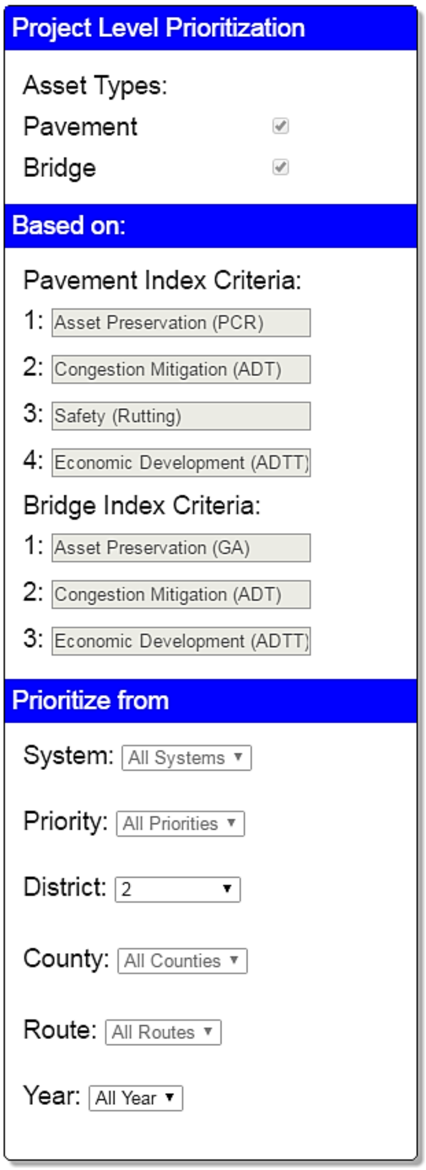
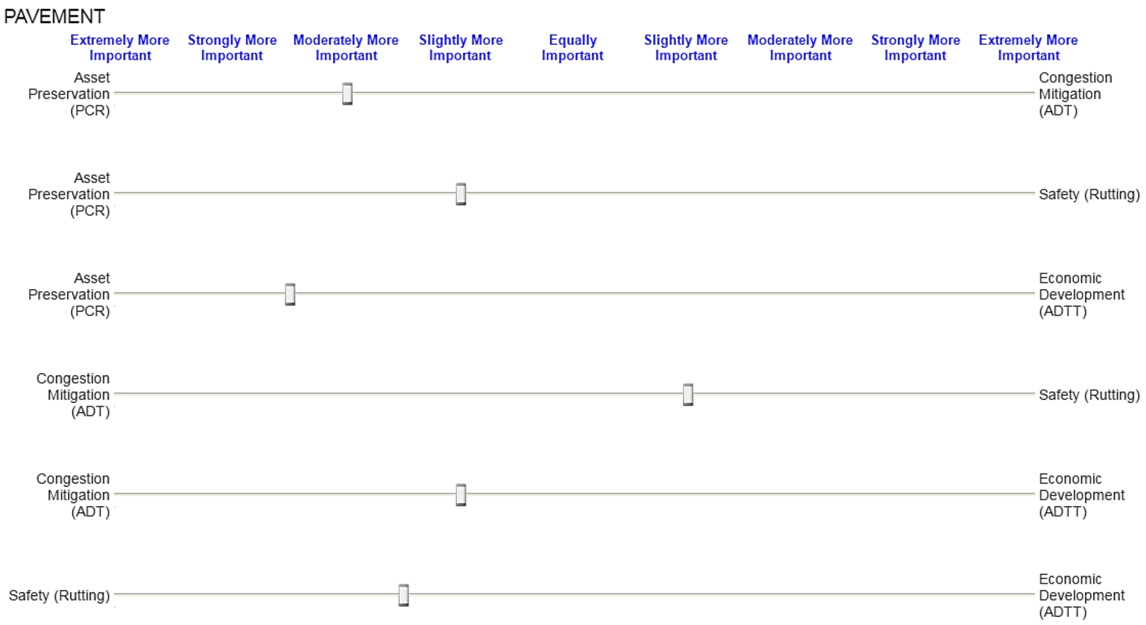
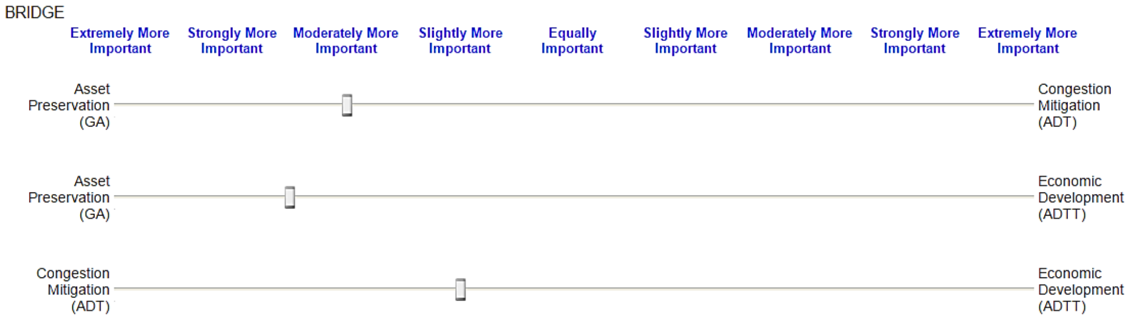


Figure A-1 Selection panel for project level prioritization

The first step is the pairwise comparison of the pavement and bridge criteria separately.



(a)

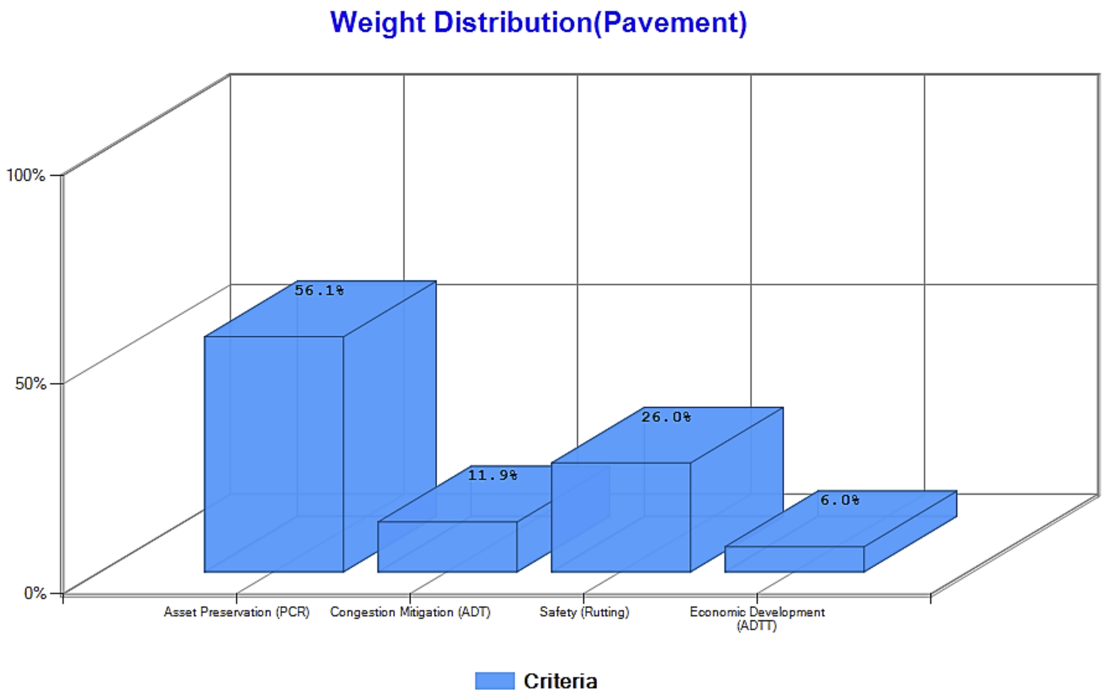


(b)

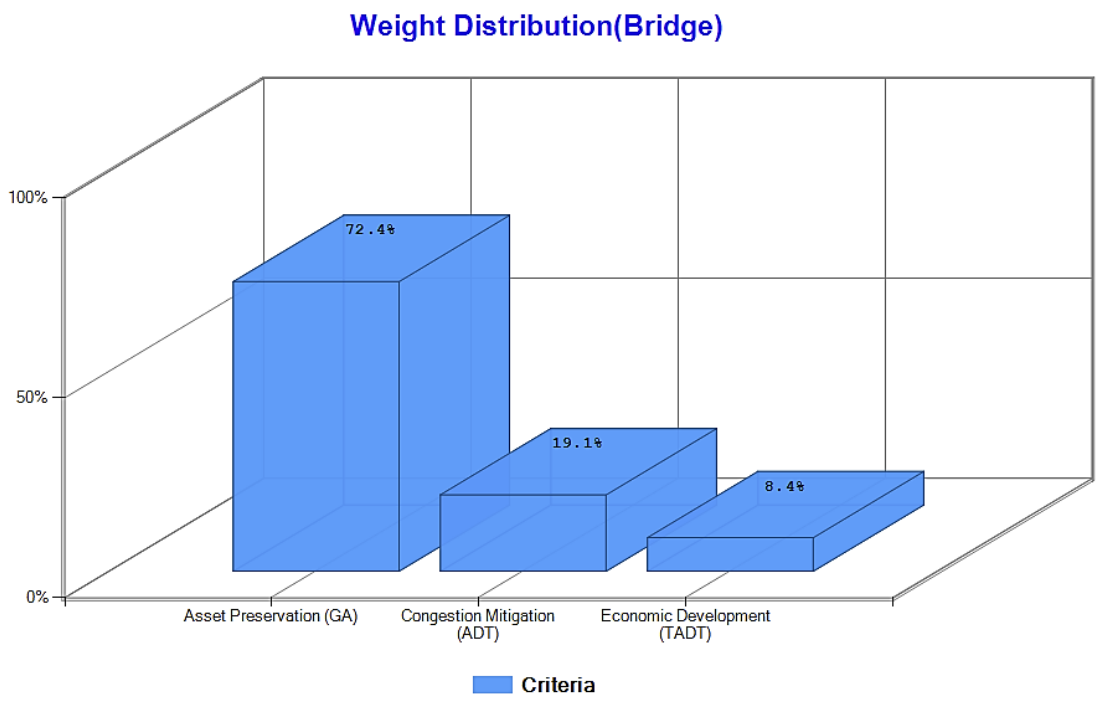
Figure A-2 Pairwise comparison of the asset criteria: (a) Pavement criteria (b) Bridge criteria

The "Show weight chart" button 

displays the weights of different criteria for pavement and bridges separately.



(a)



(b)

Figure A-3 Weight distribution from the pairwise comparison: (a) Pavement criteria weights (b) Bridge criteria weights

The “Next” button takes us to the next page showing the criteria range and weight for condition or level of criteria in project assets.

Criteria Range and Weight for Project Assets

PAVEMENT

Condition	Asset Preservation(PCR) (0-100)	Weight (0-1)	Condition	Safety (Rutting) (0-10)	Weight (0-1)
Very Good	> = 80	0.05	*Not-Acceptable*	> = 5	0.8
Fair	66 - 79	0.20			
Poor	0 - 65	0.75	*Acceptable*	0 - 4.9	0.2

BRIDGE

Condition	Asset Preservation(GA) (0-9)	Weight (0-1)
Very Good	> = 7	0.05
Fair	5 - 6.9	0.20
Poor	0 - 4.9	0.75

TRAFFIC DATA (For both pavement and bridge)

Level	AADT	Weight (0-1)	ADTT	Weight (0-1)
High	> 5000	0.75	> 750	0.75
Medium	1000 - 5000	0.20	75 - 750	0.20
Low	0 - 999	0.05	0 - 74	0.05

Change Weight

Figure A-4 Criteria range and weight for different project assets

The values on this page are default. The weights can be changed by clicking the "Change Weight" button in the bottom. This enables the weight text boxes and the user can change the weight for a different level or condition of the criteria. The user has to make sure that the sum of weights is equal to one for every criterion.

BRIDGE

Condition	Asset Preservation(GA) (0-9)	Weight (0-1)
Very Good	> = 7	0.05
Fair	5 - 7	0.2
Poor	0 - 4.9	0.75

Figure A-5 Changing the condition weight of GA

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Prioritized project list for District: 2 ; Year : All Year

Rank	PID	Year	District	#Bridges	Lane_Miles	Avg_PCR	Avg_Rutting	Avg_GA	Avg_ADT	Avg_ADTT	Pavement Weight	Bridge Weight	Project Weight
1	93918	2016	2	0	6.84	46	5.6	0	12796	802	0.763	0	0.763
2	92127	2016	2	1	19.2	60.3	5.23	7	9614	1359	0.763	0.242	0.763
3	97011	2019	2	0	2.42	61	6	0	12843	903	0.763	0	0.763
4	85266	2018	2	1	0	0	0	4	30990	2060	0	0.749	0.749
5	101327	2020	2	1	0	0	0	4	27911	1879	0	0.749	0.749
6	92095	2015	2	1	0	0	0	4	17807	2347	0	0.749	0.749
7	92331	2016	2	1	0	0	0	4	14930	1011	0	0.749	0.749
8	101556	2019	2	1	0	0	0	4	14930	1011	0	0.749	0.749
9	79901	2021	2	1	0	0	0	4	14350	970	0	0.749	0.749
10	79991	2016	2	3	0	0	0	4.3	47873	4067	0	0.749	0.749
11	85269	2016	2	1	23.62	58.4	6.53	7	6299	561	0.73	0.196	0.73
12	92361	2020	2	0	6.04	65	5.6	0	6010	720	0.73	0	0.73
13	97012	2018	2	2	5.54	63	3.9	4.5	6170	380	0.574	0.703	0.703
14	95792	2021	2	0	20.74	58.6	6.09	0	3288	661	0.665	0	0.665
15	95793	2017	2	1	19.01	60	6.09	6	3497	415	0.665	0.2	0.665
16	101281	2018	2	1	13.78	62	5.49	5	1927	215	0.665	0.2	0.665
17	88513	2015	2	0	5.12	64	5.6	0	3430	560	0.665	0	0.665
18	92128	2019	2	0	12.16	65	6	0	1410	167	0.665	0	0.665
19	84079	2017	2	1	7.58	40	6	5	420	30	0.638	0.159	0.638
20	99869	2018	2	0	1.68	51	4.2	0	25233	1705	0.607	0	0.607
21	95676	2017	2	0	2.33	55.3	1	0	17954	1213	0.607	0	0.607
22	96344	2015	2	0	5.01	56.6	4.72	0	26119	1738	0.607	0	0.607
23	85271	2016	2	1	10.08	64	2.4	7	6440	1360	0.607	0.242	0.607
24	99991	2020	2	1	0	0	0	4	4730	123	0	0.598	0.598
25	101340	2022	2	1	0	0	0	4	3060	240	0	0.598	0.598

Figure A-6 Prioritized project list with top 25 projects in District 2

The resulting table can be exported in the excel format by clicking the export to excel button.

Hyperlink: Clicking on the hyperlink for PID gives the details of the project. Suppose, clicking the PID “92127” in the second row displays the following result.

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Year	PID	District	Estimate	NLFID	Blog	Elog	MAX Pvmnt Trt Cat	Pvmnt Trt Type	SFN	MAX Bdge Trt Cat	System	Priority
2016	92127	2	$3,860,000.00	SLUCUS00020**C	0	8	Minor Rehabilitation	60 - AC Overlay with Repairs			US	G
2016	92127	2	$3,860,000.00	SLUCUS00020**C	6				4800559	Preventive Maintenance	US	G

Figure A-7 Details of the selected project